Reviewer 2

We would like to thank reviewer for useful suggestions and numerous corrections, which he introduced in our manuscript.

Below we answer his comments

The paper presents a methodology based on fluorescence lidar measurements, that allows to detect and to quantify the smoke content in upper troposphere and lower stratosphere (UTLS). The methodology is based on several assumptions which are not well validated. My major conern is about the methodology to retrieve the values of N_F S_F V_F (lines 193-199, and 217-219). For instance, the authors explain that they retrieve the N, S, V values from optical data $3\beta+2\alpha$. Then they introduce C_N, C_S C_V parameters (eq. 3), based on the previous retrieval of the β_F values. The state that these factors allow the estimation of N, S, V from fluorescence backscatter, although N, S, V values are already known from the optical data $3\beta+2\alpha$. This is a point of confusion.

To prevent possible confusion, in revised manuscript we use notations *N, S, V* for concentrations derived from $3\beta+2\alpha$ observations. For smoke concentration, obtained from fluorescence we use notations N^S, S^S, V^S. Values of *V* and V^S for example, can be close inside smoke layer. But inside cirrus clouds V^S presents just small fraction of *V*.

Another issue is how they retrieve the N_F S_F V_F values. This is not at all clear in the manuscript. Do these values come from the comparison with the N S V ones from different cases studies?

To simplify understanding of calculation steps, we followed reviewer suggestion and added in the revised manuscript Appendix with corresponding flow chart.

<u>Appendix A.</u> Estimation of smoke parameters from Mie-Raman and fluorescence lidar measurements.

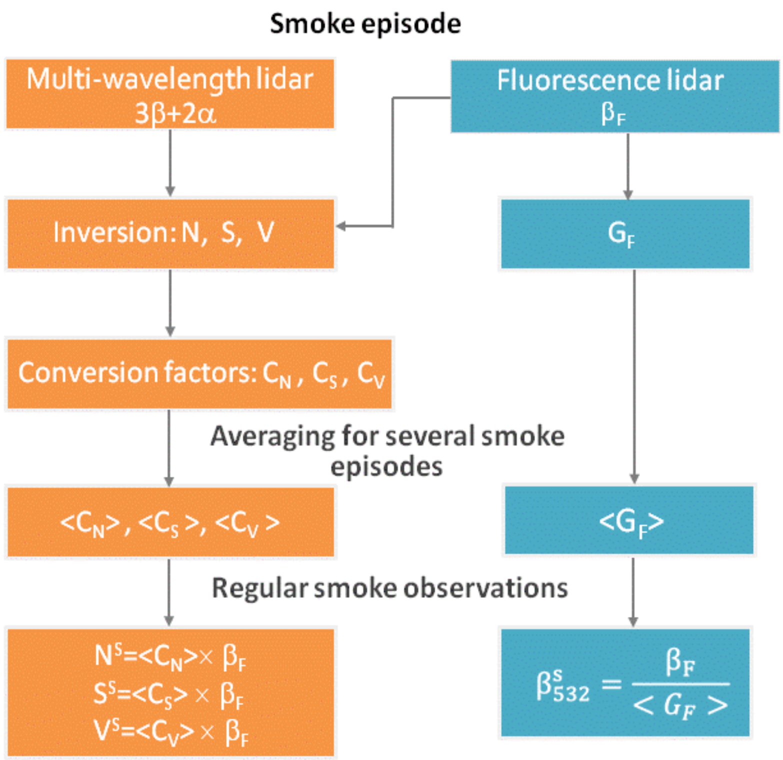

Fig.A. Flow chart showing the main steps of the procedure of smoke parameters estimation from multiwavelength Mie-Raman and fluorescence lidar measurements. Procedure includes the following steps. (i) For a strong smoke layer the 3β+2α data set, derived from multiwavelength Mie-Raman lidar observations, is inverted to the particle number N, surface S and volume V density. (ii) Conversion factors C_N, C_S, C_V are calculated from Eq.(3) by using the fluorescence backscattering coefficient β_F. (iii) Different smoke events are analyzed to get mean values of conversion factors $<C_N>$, $<C_S>$, $<C_V>$. These mean values are used to estimate smoke concentration in weak layers in UTLS and inside cirrus clouds in regular observations. The mean value of smoke fluorescence capacity $<G_F>$ allows estimation of smoke contribution β^s_{532} to the total backscattering coefficient β_{532}.

We hope, that now it will help the reader.

These points need clarification, along with putting error bars in all parameters shown in the various profiles.

Error bars are added to the plots

Some minor corrections have to be made, based on the uploaded annotated manuscript. In many places the article "the" is missing. The English text should be revised, as in some places it is unclear.

We followed reviewer suggestions and introduced modifications in the manuscript.

PS. I propose to introduce in an appendix or supplement a flow chart showing each calculation step for every retreived parameter [eg. (3β+2α) --> N, S, V; βF --> βS 532 ,etc]. This will facilitate the reader to follow the estimation of the different parameters.

Yes, Appendix is added

Ln. 264 "We simply assume a constant ice supersaturation of around 1.45 during a time period of 600 s (upwind phase of a typical gravity wave in the upper troposphere)".
Where this assumption is based on? Is there a reference paper to cite?
Ln. 269. *"Ice crystal number concentration of 1-10 L^{-1} are typical values in cirrus layers when heterogeneous ice nucleation dominates."*
Provide reference papers

It is well accepted that the supersaturation levels for homogeneous ice nucleation need to be about 1.5 to 1.6 to start homogenous freezing. In the presence of INP, nucleation may start at supersaturation level of 1.3 - 1.45 and the supersaturation stops to increase, except the updraft is very strong, which is not the case in the upper troposphere. These mechanisms are discussed in publications listed below. Corresponding references are added to the revised manuscript.

Ansmann, A., Mamouri, R.-E., Bühl, J., Seifert, P., Engelmann, R., Hofer, J., Nisantzi, A., Atkinson, J. D., Kanji, Z. A., Sierau, B., Vrekoussis, M., and Sciare, J.: Ice-nucleating particle versus ice crystal number concentration in altocumulus and cirrus layers embedded in Saharan dust: a closure study, Atmos. Chem. Phys., 19, 15087–15115, https://doi.org/10.5194/acp-19-15087-2019, 2019.

Ansmann, A., Ohneiser, K., Mamouri, R.-E., Knopf, D. A., Veselovskii, I., Baars, H., Engelmann, R., Foth, A., Jimenez, C., Seifert, P., and Barja, B.: Tropospheric and stratospheric wildfire smoke profiling with lidar: mass, surface area, CCN, and INP retrieval, Atmos. Chem. Phys., 21, 9779–9807, https://doi.org/10.5194/acp-21-9779-2021, 2021.

Engelmann, R., Ansmann, A., Ohneiser, K., Griesche, H., Radenz, M., Hofer, J., Althausen, D., Dahlke, S., Maturilli, M., Veselovskii, I., Jimenez, C., Wiesen, R., Baars, H., Bühl, J., Gebauer, H., Haarig, M., Seifert, P., Wandinger, U., and Macke, A.: Wildfire smoke, Arctic haze, and aerosol effects on mixed-phase and cirrus clouds over the North Pole region during MOSAiC: an introduction, Atmos. Chem. Phys., 21, 13397–13423, https://doi.org/10.5194/acp-21-13397-2021, 2021.

Sullivan, S. C., Morales Betancourt, R., Barahona, D., and Nenes, A.: Understanding cirrus ice crystal number variability for different heterogeneous ice nucleation spectra, Atmos. Chem. Phys., 16, 2611–2629, https://doi.org/10.5194/acp-16-2611-2016, 2016.